Superflare WS 2016@Kyoto

CMEs of solar superflares

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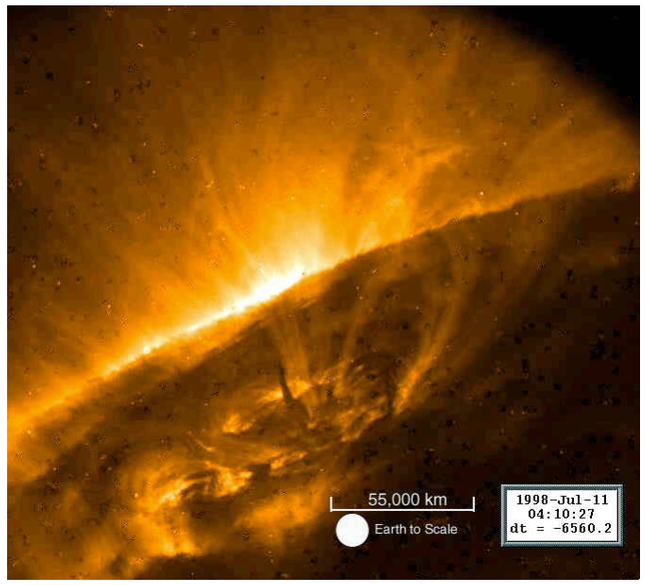
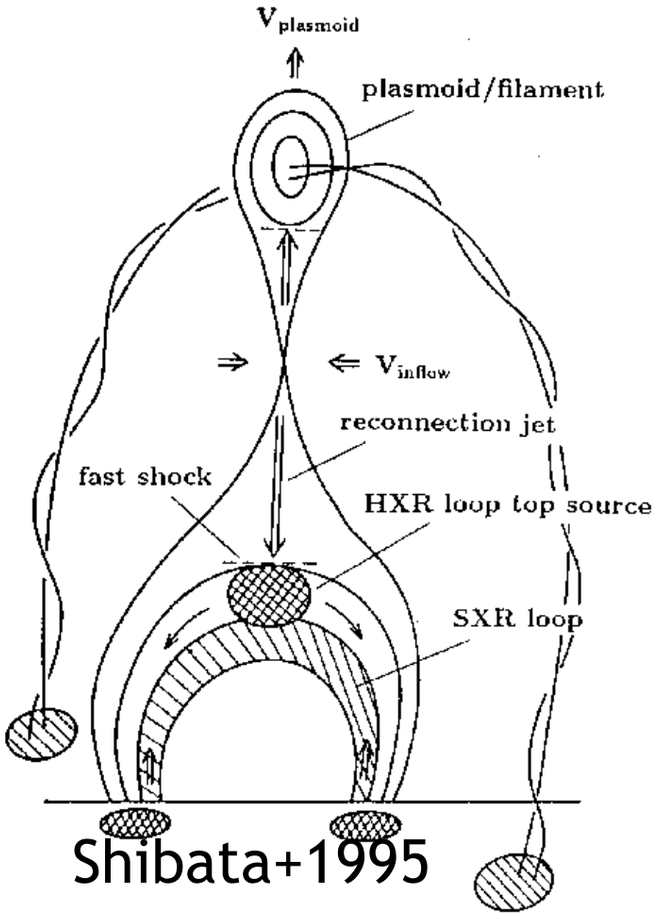
Solar Flares and Coronal Mass Ejections (CMEs)

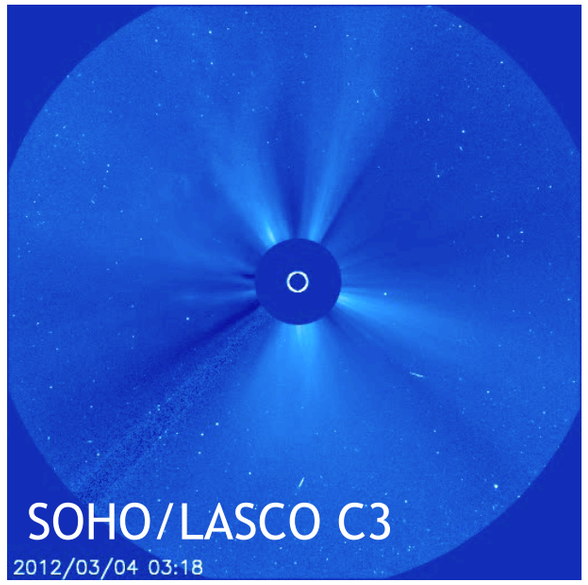
Solar Flares

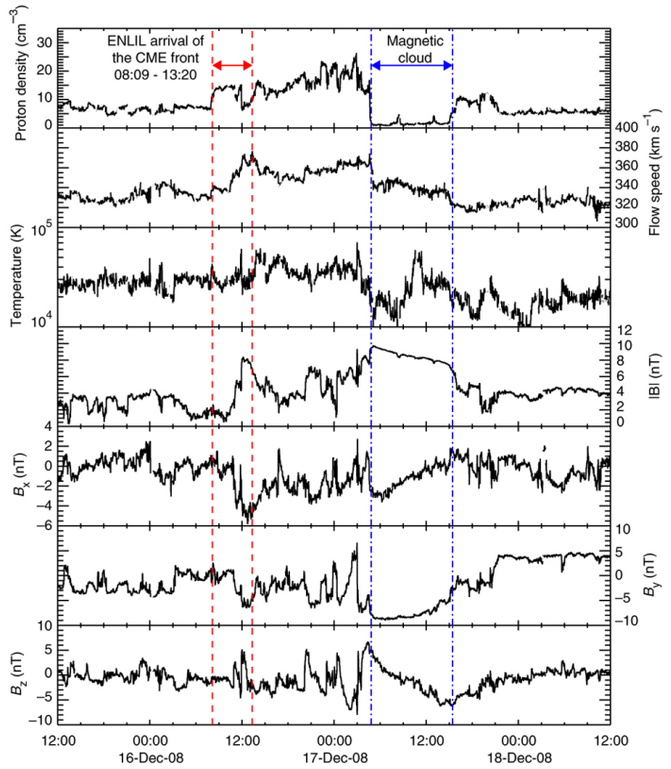




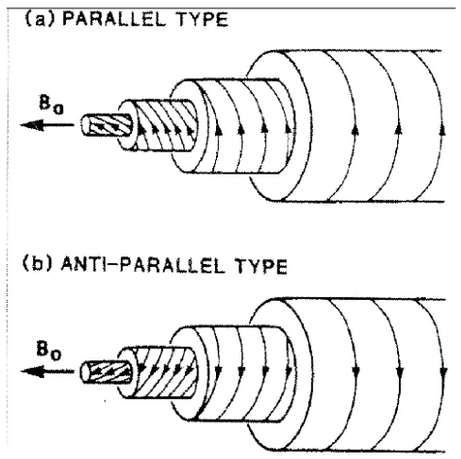
Shibata+1995

CMEs

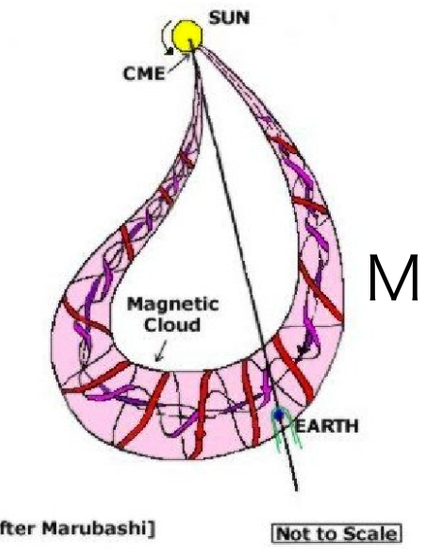




Byrne+ 2010



Marubashi + 2002



Magnetic flux rope

shock wave

Southward Bz causes Geomagnetic storms

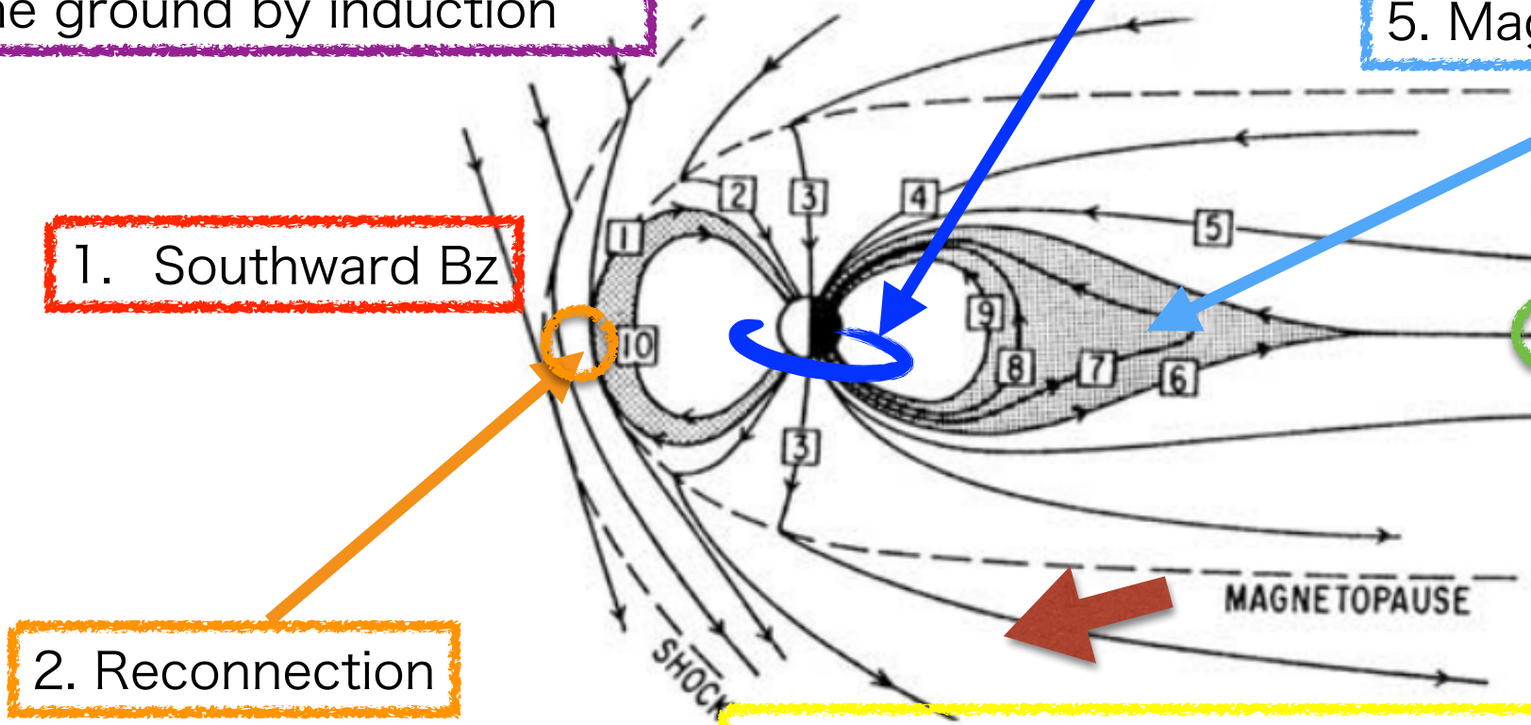
Geomagnetic storm

7. Decrease of geomagnetic field on the ground by induction

6. Ring current (westward)

5. Magnetic field lines shrink

1. Southward Bz



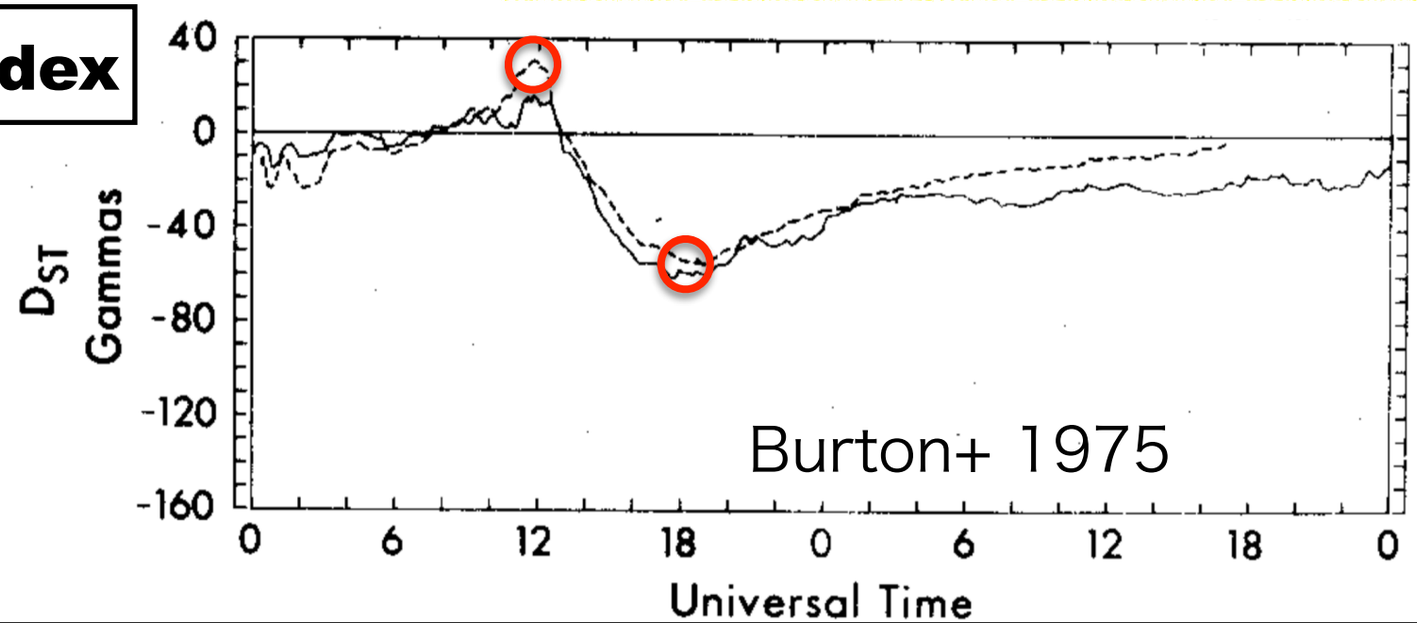
4. Reconnection

2. Reconnection

Axford 1969

3. Transport of magnetic field lines

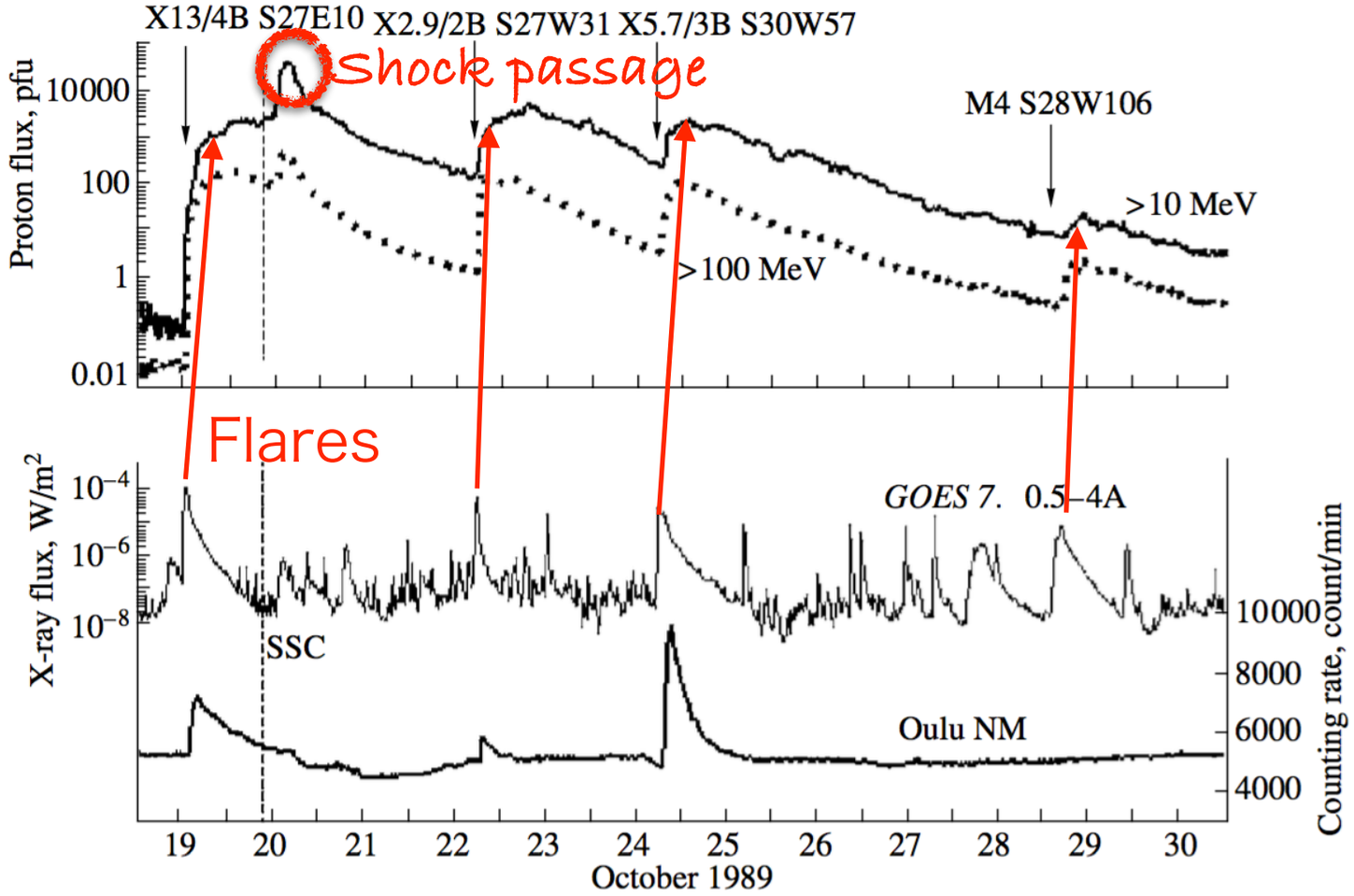
DST index



Burton+ 1975

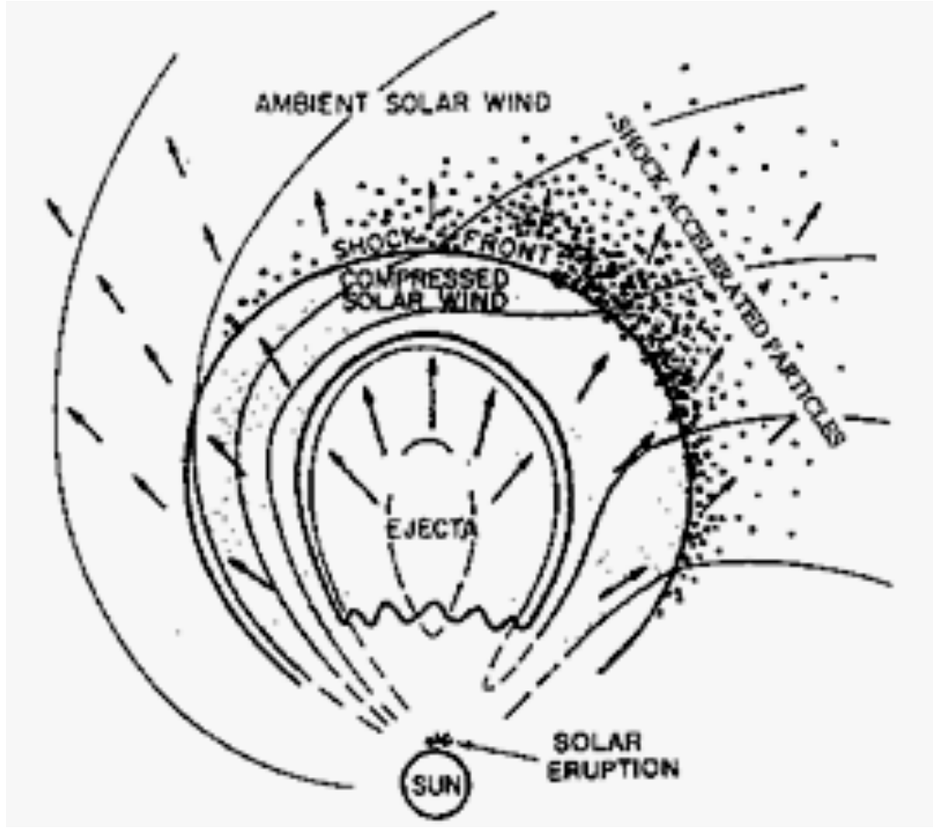
CMEs and solar proton events

Solar proton events (SPEs)
are caused by CMEs



Belov+2005

Protons are mainly accelerated
at the CME shock front



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Mass and Velocity of "super" CMEs

(1) : Gravitational stratified atmosphere (with L >> H)

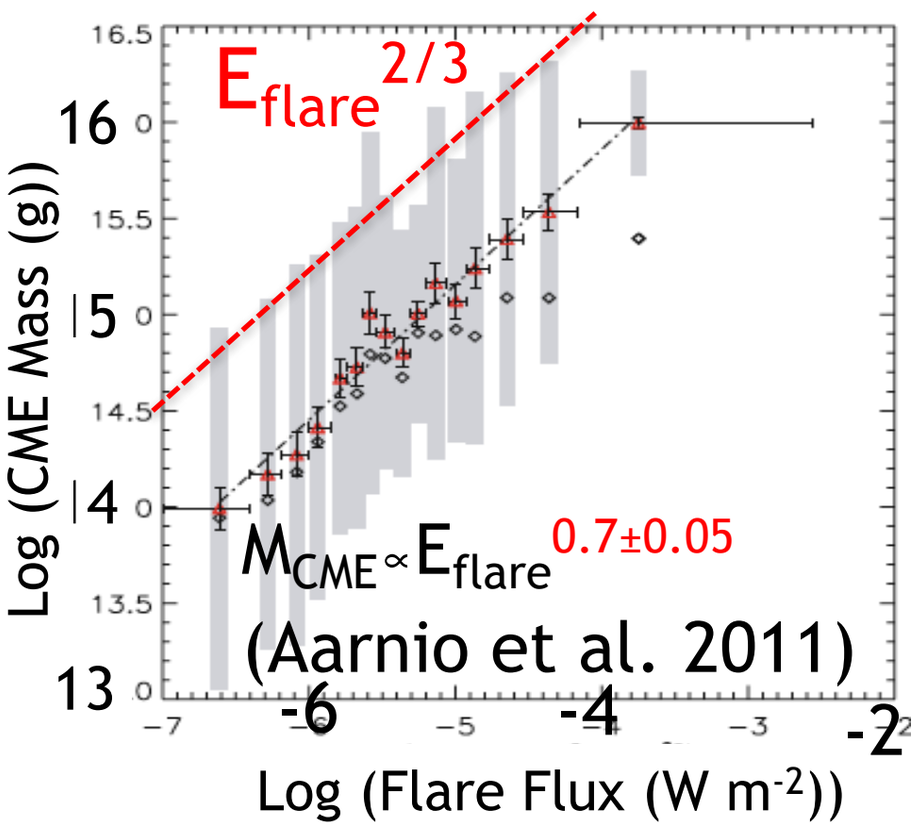
$$M_{cme} = L^2 \int_0^L \rho_0 \exp(-\frac{z}{H}) dz \sim \rho_0 L^2 H \quad \underline{\propto L^2}$$

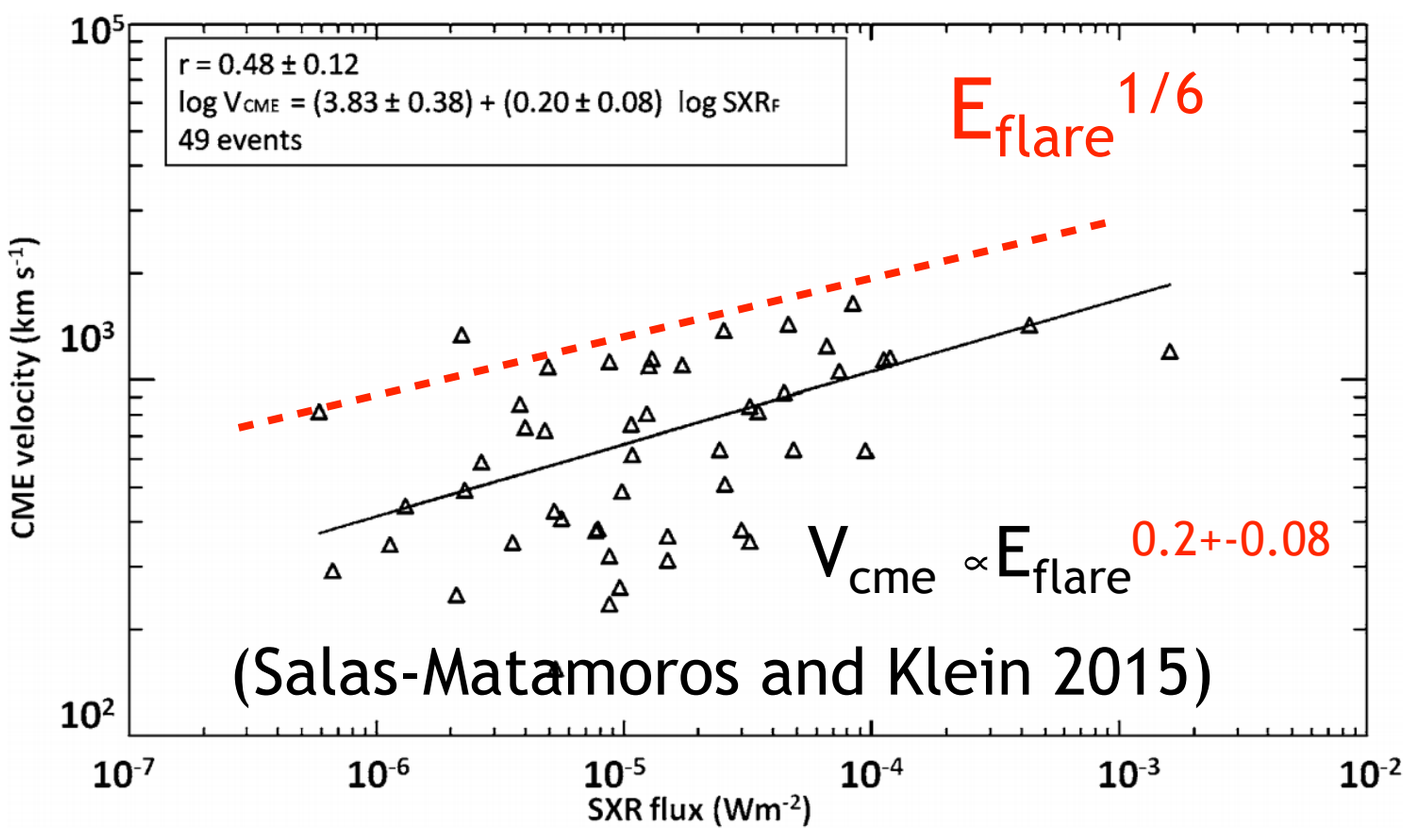
(2) : CME kinetic energy ~ flare released energy (cf. Emslie et al. 2012)

$$E_{flare} \sim E_{cme} = \frac{1}{2} M_{cme} V_{cme}^2 \sim E_{mag} = f \frac{1}{8\pi} B_0^2 L^3 \quad \underline{\propto L^3}$$

=> $M_{cme} \propto L^2 \propto E_{flare}^{2/3}$, $V_{cme} \propto L^{1/2} \propto E_{flare}^{1/6}$

=> $V_{CME,X1000}$ ~3000*(100^1/6)~ 6000 km/s for example…



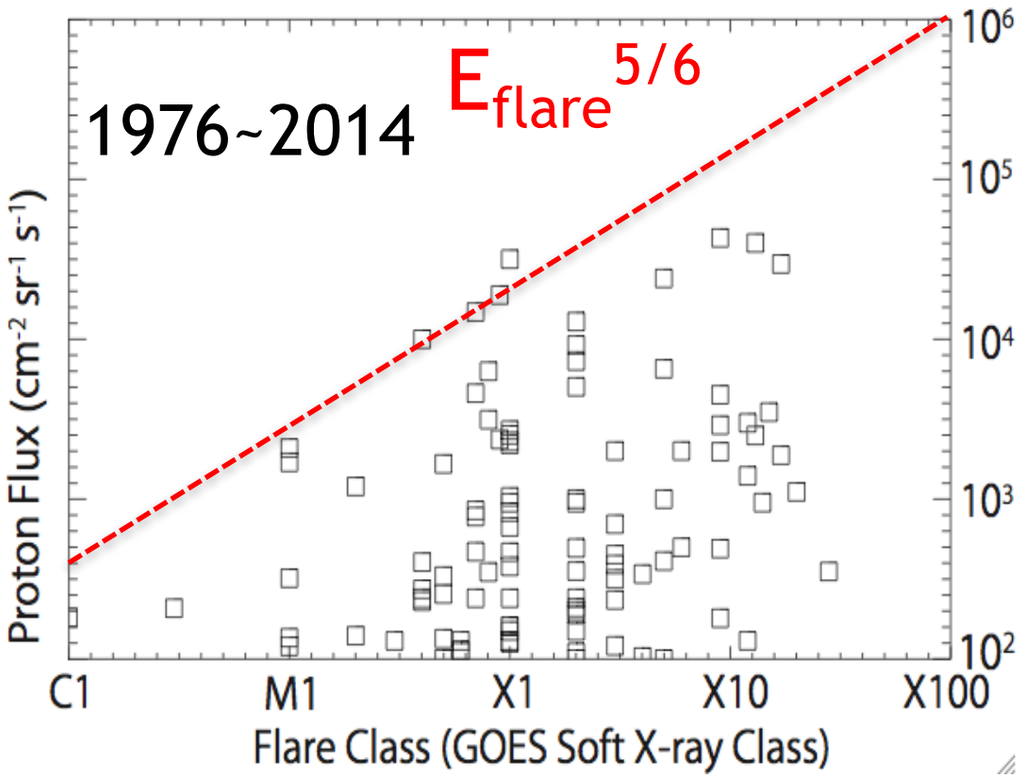


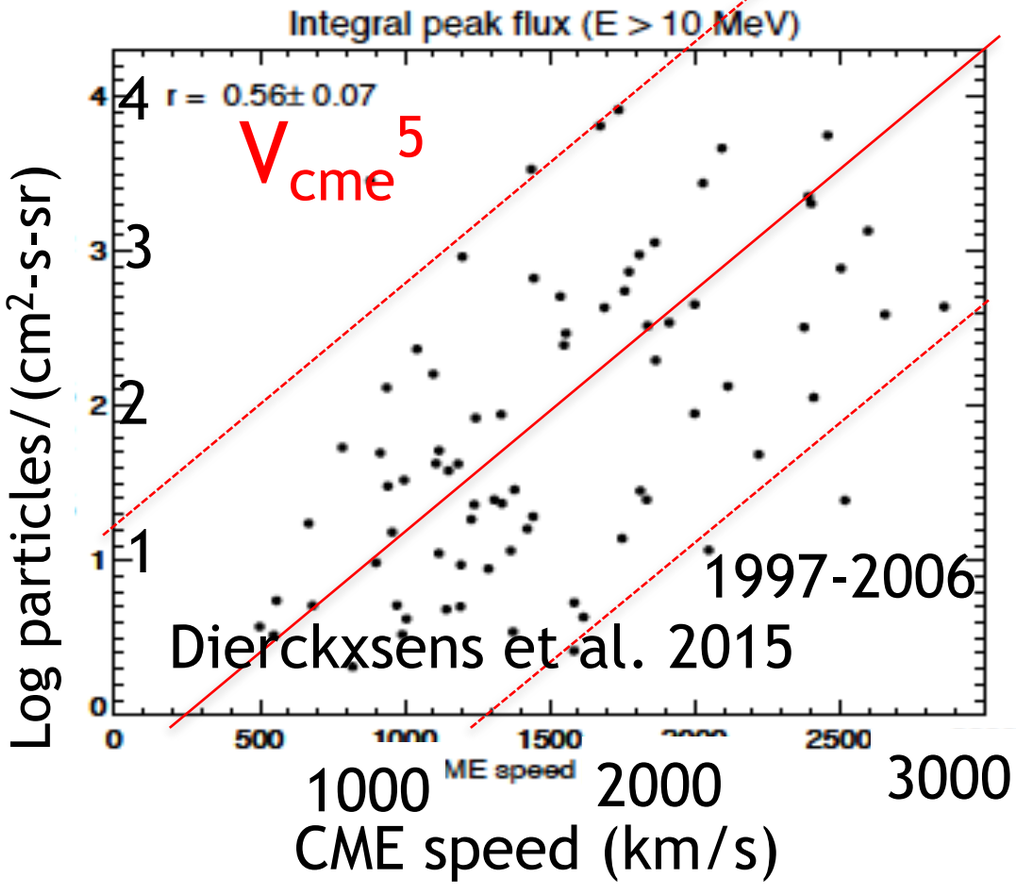
Estimation of proton flux of “super” proton events

(3) : Energetic proton energy ∝ Flare released energy

$$E_P \propto I_P\, t_{CME} \propto E_{flare}$$

(1), (2), (3) ⇒ $I_P \propto E_{flare}^{5/6} \propto V_{cme}^{5}$



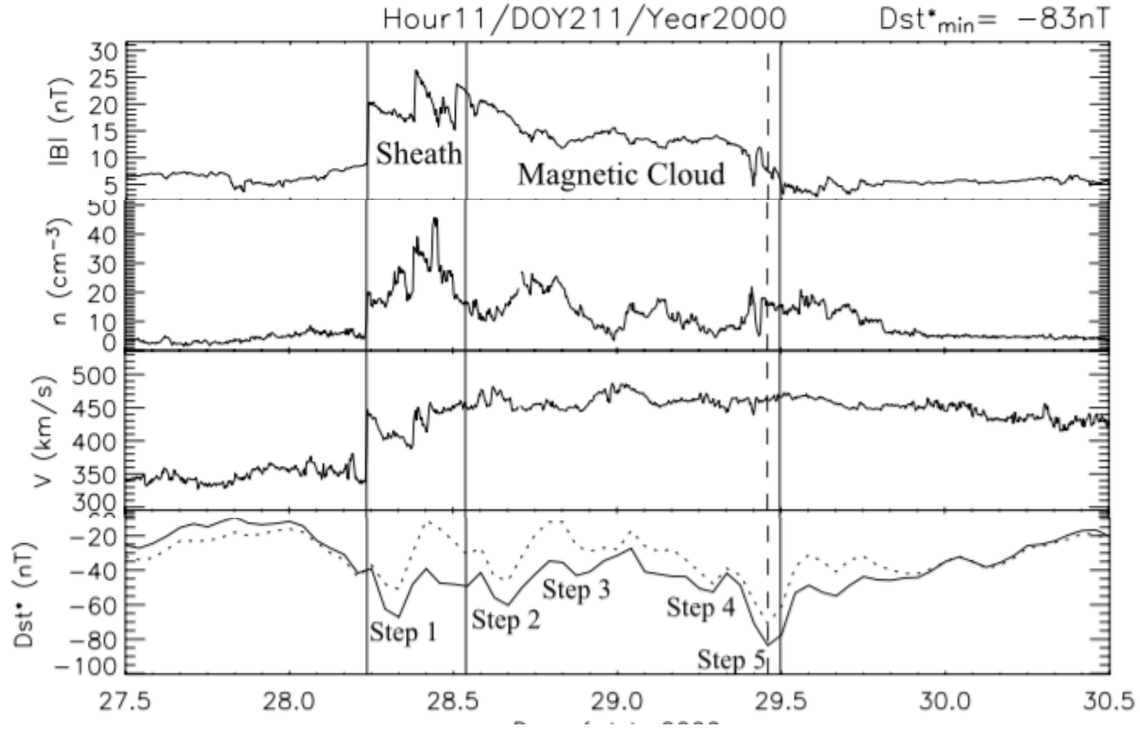


➔upper-limit of I_{SEP} ;
$I_{SEP,X1000}$ < 6.8*10^6 pfu,

➔upper-limit of I_{SEP} ;
$I_{SEP,X1000}$ < 4.9*10^6 pfu,

Magnetic field strength of “super” CMEs at 1AU

Geomagnetic storms caused by CME passage



Shock front

CME	Sheath	Interplanetary
$B_{cme}^2/8\pi$ ~	P_{seath}	~ $\rho_{sw}*(v_{cme}-v_{sw})^2$

Dynamical Pressure ~ Magnetic Pressure

$$B_{cme}^2/8\pi = \rho_{sw}*(v_{cme}-v_{sw})^2$$

n_{sw} = 1(/cc)

V_{sw} = 500 (km/s)

without considering deceleration of CME as an estimate for upper limit…

	CMEs	“Super” CMEs
Flare Class	X10	X1000
AR Size	100 Mm	460 Mm
M_{cme}	$7*10^{16}$ g	$1.5*10^{18}$ g
v_{cme}	3000 km/s	6000 km/s
B_{cme}@1AU	160 (nT)	360 nT

=> May be used to estimate Dst index, and so forth.

Summary

Scaling relations

Mass and speed, magnetic field @ 1AU

$$M_{cme} \propto L^2 \propto E_{flare}^{2/3},\ V_{cme} \propto L^{1/2} \propto E_{flare}^{1/6},\ B_{cme,upper\text{-}limit}@1AU \propto V_{cme}^{1}$$

Energetic proton flux in SPE

$$I_P \propto E_{flare}^{5/6} \propto V_{cme}^{5}$$

Estimated properties

	CMEs	“Super” CMEs
Flare Class	X10	X1000
AR Size	100 Mm	460 Mm
B_{cme}@1AU	160 nT	360 nT
M_{cme}	$7*10^{16}$ g	$1.5*10^{18}$ g
CME speed	3000 km/s	6000km/s
Ip	10^5 pfu	5x10^7 pfu